JOURNAL

of

STEEL CASTINGS RESEARCH

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STEEL FOUNDERS' SOCIETY OF AMERICA

NUMBER 15 SEPTEMBER, 1959

JOURNAL OF STEEL CASTINGS RESEARCH

Number 15 **September, 1959**

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SERVICE REQUIREMENTS SET QUALITY LEVELS*

by

Kenneth L. Selby**

In the steel foundry industry, inquiries and/or orders for castings designed by others generally fall into one of three categories as follows:

1. Those which provide very meager information for the manufacturer's guidance, often little more than a drawing of the item required.
2. Those which include chemical and physical properties, usually by reference to generally recognized specifications which also cover required heat treatment, specimen tests, workmanship, finishing, etc.
3. Those for which very elaborate specifications have been specially prepared, often to the extent that they are difficult of interpretation by the manufacturer. Presumably the intent of such specifications is to cover the service requirements of the castings.

The designer of a casting should be, and usually is, fully aware of the purpose to be served, and his knowledge of the intended service requirements should be shared by all who are involved in producing the finished product. It is not desirable and should not be necessary to burden specifications with this important information, particularly because of the widely different uses of the many casting designs involved. In the majority of cases one of the existing commercial specifications would serve satisfactorily to cover the basic requirements.

When the intended service application conditions are known, the manufacturer is then in position to apply the foundry techniques best suited to obtain the desired results. The gates and risers can be positioned to avoid jig locations when required for machining operations. Foundry finishing of castings can be reduced to a minimum when it is known in advance where finishing may be required due to close clearances in assembly or where contact is made with other components. The quality control procedures necessary to obtain consistently satisfactory castings for the intended purpose can be determined and instituted.

Obviously these procedures may differ widely for various types of castings, depending on the nature and severity of the conditions imposed on a given design in service. For instance, castings of simple design intended for static loading only would require a minimum of exploratory analysis in the quality control procedures. Conversely, castings of more complex design, involving compound stresses and subjected to severe dynamic loading in service, would require the application of much more elaborate qualitative control to insure a uniformly satisfactory product for this purpose.

The economics involved in the foregoing will be immediately apparent since there would be an appreciable cost differential in the two cases cited. Therefore, only those quality-control procedures necessary to insure castings suitable for the intended purpose should be utilized by the manufacturer, thus minimizing the expense without sacrificing quality. These ideals can be achieved only by complete cooperation between the purchaser and manufacturer and full knowledge of service requirements by both.

Most, if not all, modern steel foundries have available numerous facilities used for exploratory purposes, including X-ray or Gamma-ray and magnaflux to locate defects which may be present in first-run castings and to determine when they have been eliminated. Stresscoat and SR-4 strain gages are used to determine location and magnitude of significant stresses under simulated service loading conditions. Photoelastic studies may also be employed to indicate desirable design improvements. These methods used to improve foundry techniques and theoretical design augment the visual inspection procedures applicable to all production castings throughout the entire manufacturing cycle.

A few of many instances will now be cited where service requirements have determined the quality level needed to meet the demand. All of the castings designs used as illustrations are made of grade B normalized steel, and are manufactured under the same basic specifications. This material has a minimum yield strength of 38,000 psi and ultimate strength of 70,000 psi.

Figure 1 shows a column base casting of simple design used to sustain a constant compression load. For castings of this material statically loaded in service, a design stress of 25,000 to 30,000 psi can be used which would provide a safety factor of 2½ to 3. Such castings would require no special attention but would be cast and finished according to normal foundry practices with usual visual inspection. Repairs by welding would not be detrimental.

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*Presented at the Conference on Steel Castings, April 16, 1958, sponsored by the Corps of Engineers, Fort Belvoir, Virginia.

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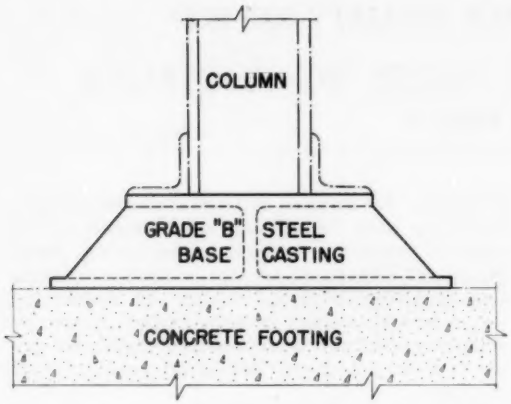

Figure 1—Column base casting used in a static loading application.

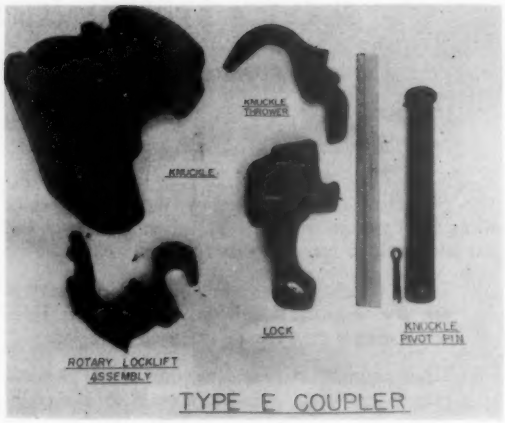

Figure 3—Operating parts of a Type E coupler.

Figure 2—A.A.R. Standard cast Type E coupler body.

Figure 2 shows the cast body of one of several types of A.A.R. Standard couplers, which will be found at the ends of every car and locomotive in American railway service, and is used to couple and hold the units together in a train. Since the original concept of this design over forty years ago, a technical committee of coupler manufacturers has devoted its skill to refining and improving the design to keep pace with the steadily increasing demands of service. The coupler is subjected to severe dynamic forces, both tension and compression, and the space limitations are such that the overall size is restricted. For this reason every pound of metal must be distributed where it will be of greatest benefit.

Many laboratory tests have been devised and conducted in efforts to preclude possible failures, but no satisfactory substitute for service-experience has yet been found to learn what is needed. High quality standards must be and are maintained throughout all phases of manufacture. Although the specifications do not require it, periodic X-ray and magnaflux inspections are made. Physical tests on complete couplers are also made by each manufacturer at regular intervals as part of quality control procedure. There are many important surfaces in the coupler which must be accurately formed and controlled, and this is likewise true of the operating parts shown on Figure 3, that must fit into the head and perform their required functions. A multiplicity of specially designed gages are used on all castings and still others for periodic checking only. The inspection requirements generally are well established on a basis mutually satisfactory to the manufacturer and purchaser. Welding of minor defects to improve general appearance is permitted, but repairs of major defects which might impair the strength if they were not welded are prohibited.

The design of the coupler head presents a rather complex problem for theoretical stress analysis, but by careful blending of the wall sections to avoid stress concentrations, a well balanced design has resulted. At present the design safety factor is about 4 based on normal service loads. A higher factor would be desirable for better protection against unusual and unpredictable conditions. This of course, is possible by employing higher strength steels and appropriate heat treatment which has already been done experimentally in abnormally heavy service.

The availability of electronic equipment in recent years now makes possible an accurate evaluation of dynamic forces as well as the resulting stresses in practically any type of structure. Figure 4 shows one such means used to measure the dynamic forces imposed on car couplers when cars are impacted against each other at various velocities. This special dynamometer coupler, cast in high tensile steel, is provided with an "H" section in the middle of the shank. A number of SR-4 electric strain gages are mounted on various surfaces of this section, both internally and

Figure 4—Dynamometer coupler containing an "H" section in the middle of the shank cast in high tensile strength steel.

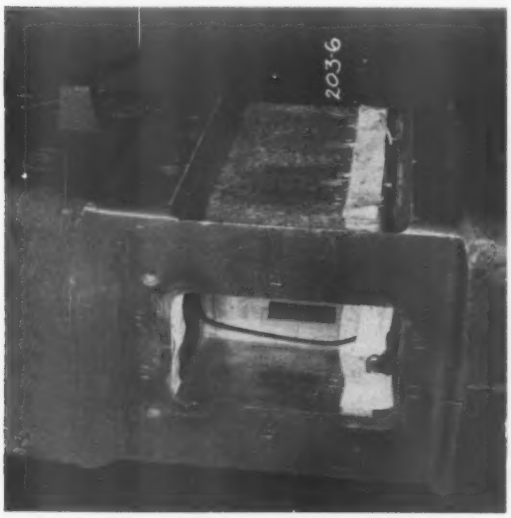

Figure 5—Close-up of center "H" section of the coupler of Figure 4 mounted with SR-4 strain gages.

Figure 6—Test train equipped with dynamometer couplers and other testing devices.

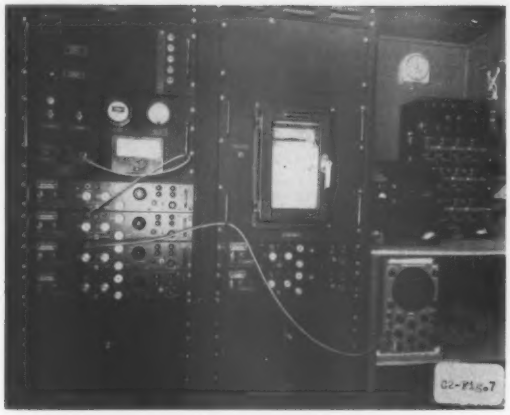

Figure 7—Electronic recording instruments in test train.

Figure 8—Side frame in complete railway truck assembly.

externally, which can be seen more clearly in the close-up view Figure 5. The existing coupler on the end of the car to be impacted is replaced with this dynamometer coupler and when struck by the other car, at accurately measured velocities; the impact force in pounds is recorded on an oscillograph. Compression forces of a million pounds and over have been recorded at impact velocities not uncommonly encountered in railroad classification yards.

This knowledge, not previously available, is of great value to the designer of various railway car components which are subjected to these forces in service and clearly indicates the necessity of maintaining a high quality level in the production of any castings involved.

Dynamometer couplers and other measuring devices are also being used on cars specially instrumented for train service studies. One such test train is shown in Figure 6 as viewed from the air. One of the caboose cars houses the electronic instruments used for recording results. Figure 7 is a view of some of these instruments within.

Another casting of rather intricate design is the side frame of a railway car truck, one of which is shown in Figure 8 on a complete truck of a car in

Figure 9—Side frame mounted with SR-4 strain gages undergoing static testing.

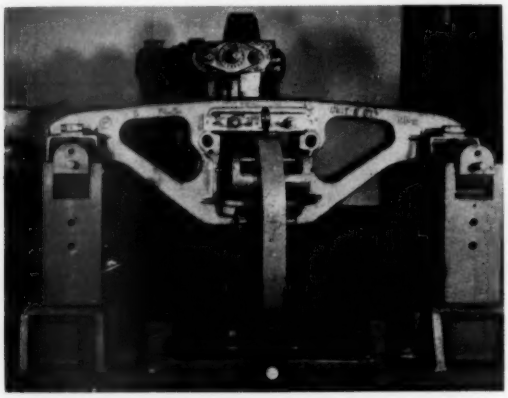

Figure 10—Side frame being tested under conditions of dynamic loading.

service. The entire weight of the car and contents is carried on four of these frame castings which are subjected reapeatedly during service life, to several dynamic forces acting singly or in combination.

The majority of the side frames in service are made of grade B steel and are manufactured under the same basic A.A.R. specifications as are couplers and many other steel castings used on cars. However, there is one important difference in that two specimens of each new side frame design made by any manufacturer must be subjected to prescribed static tests, and four additional specimens to a dynamic fatigue test. When these requirements have been met the manufacturer is assigned an approval number by the A.A.R. which must appear on all frames of that design produced to be acceptable in interchange service.

Prior to application for approval a complete stress analysis is usually made by the manufacturer to verify

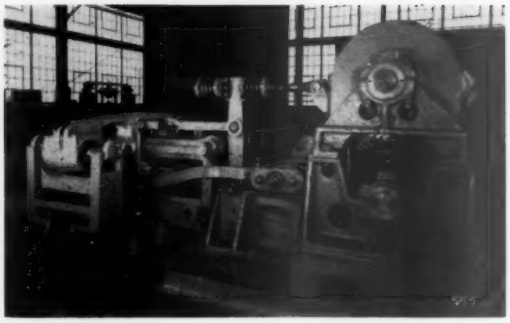

Figure 11—Rear view of the side frame of Figure 10.

theoretical stress calculations. Stresscoat and SR-4 strain gages are used for this analysis under static loading conditions simulating service. A frame undergoing a test of this kind is shown in Figure 9.

The dynamic tests are particularly exacting from the standpoints of design and foundry technique. All metal sections must be as uniform as possible and smoothly blended with ample radii throughout to avoid localized stresses. Every means available is used in the foundry to refine manufacturing practices in order to obtain the highest possible quality level for subsequent production when the design is approved. A side frame undergoing the dynamic fatigue test in one of the two available machines is shown in Figure 10 viewed from the front, and in Figure 11 from the rear. Vertical, lateral and twist loads are applied at regular intervals, all reaching their peak simultaneously during each cycle. A complete test on each frame can be made in several days and represents the equivalent of approximately 20 years of service.

Service failures of this vital truck component result in costly damage and possible serious injury or death. Such failures were not uncommon before the fatigue test became a requirement for A.A.R. approval but have been exceedingly rare since that time. For theoretical design calculations, in accordance with A.A.R. design formulae, the maximum combined stress is 16,000 lbs/sq.in. for grade B steel. The required minimum ultimate strength of side frames under vertical static load is 12.5 times the specified axle load limit, which varies in proportion to journal size, and thus establishes this figure as the safety factor for all frame sizes.

Here again, service requirements have indicated the quality level necessary for satisfactory production of these castings which once established, must be rigidly adhered to by the manufacturer. The benefits which accrue to all concerned through full knowedge of service requirements should be readily apparent from the few cases herein cited. The objective of the supplier and consumer are one and the same, namely, satisfactory service performance.

OXYGEN INJECTION IN STEELMAKING PRACTICE

by

T. A. Cosh* and K. Knaggs**

The following article represents a continuation of the research done by the British Steel Castings Research Association reported in "Oxygen Injection in Foundry Steelmaking Practice", by K. Knaggs, which was published by SFSA in the Journal of Steel Castings Research, No. 12, September 1958.

Results of a survey on utilization of oxygen reported by Knaggs[1] showed large differences in oxygen consumption from foundry to foundry and even within the practice of single foundries. Oxygen input rates varied between 40 cu.ft./minute/ton and 90 cu.ft./minute/ton; specific oxygen consumption (S.O.C.) was found to vary between 4.0 cu.ft./0.01 percent C/ton and 101 cu.ft./0.01 percent C/ton, and the calculated efficiency of oxygen utilization for metalloid removal varied between 20 percent and 127 percent. While efficiencies in excess of 100 percent can arise when the FeO in the slag diminishes during the injection period and contributes oxygen to the system, some anomalies arise from erroneous analyses. The actual oxygen used per ton of steel varied from 13.5 cubic feet to 370 cubic feet with an average of 119 cu.ft./ton of steel. This last-mentioned fact can be, to some extent, accounted for by differences in metalloid content at meltdown; that is, if silicon or manganese is high at meltdown, or if there is an excess of chromium in the scrap, then particularly at low temperatures, these elements will be oxidized preferentially to the carbon, because of the greater affinity which they have for oxygen. Generally, the poorest efficiencies were associated with the extremes of oxygen input.

Factors Affecting The Efficient Use of Oxygen

The volume of oxygen required is dependent mainly on: (a) the concentrations of the various elements present which will take part in the reactions; and (b) the relative affinities of these elements for oxygen at the temperature of injection.

Knaggs[1] derived a factor called the "cumulative potential" from these two considerations and showed that for a particular oxygen input, efficiency was dependent on the cumulative potential. In other words, the more work that the oxygen had to do the better it would do it or, alternatively, for a fixed level of cumulative potential, the efficiency falls as the volume of oxygen per ton of steel increases beyond a particular value. Since this conclusion was based on heats made in production foundries, it is tantamount to stating that sufficient data were available to indicate that a large amount of oxygen is being wasted.

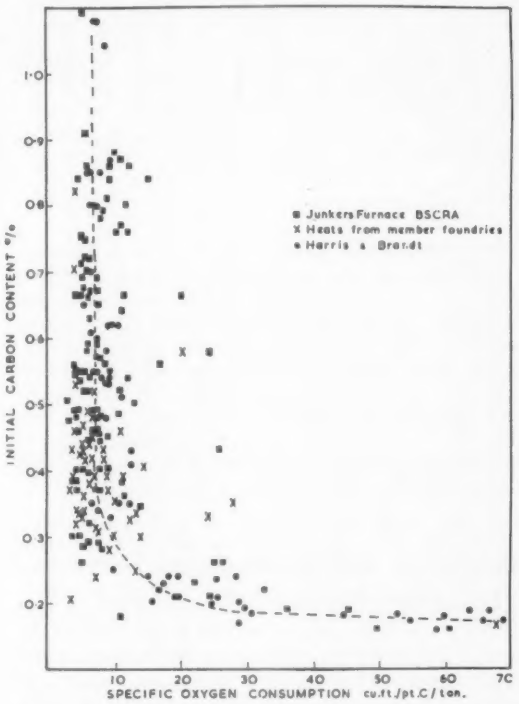

Figure 1—Relationship between specific oxygen consumption and initial carbon content.

Improving the Efficiency of Oxygen Usage

Ideally, the efficiency with which oxygen is used could be improved if it were possible to analyze the bath metal prior to injection and if one could predict, by a method similar to that used in calculating the cumulative potential, the effect of injection of a fixed volume of oxygen. That is not possible, mainly because sufficiently rapid methods of analysis are not available, and some other method has to be sought.

The data published previously by other workers, those obtained from the survey of oxygen injection practice in member foundries, and those obtained from over 100 heats made in the 600-pound capacity resistor rod furnace in the B.S.C.R.A. Research Station, are included in the graph of specific oxygen consumption versus initial carbon content, Figure 1.

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**Senior Investigator, B.S.C.R.A.

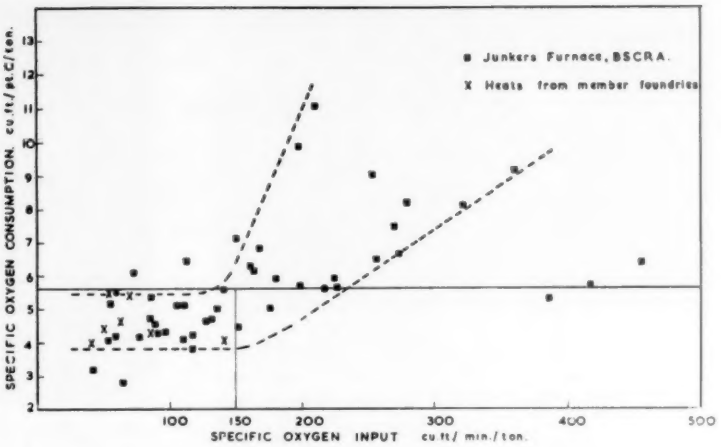

Figure 2—Relationship between specific oxygen input and net specific oxygen consumption for temperatures in excess of 2876 degrees F and carbon contents greater than 0.25 percent (initial) and 0.10 percent (final).

This graph takes no account of any of the variables—temperature, specific oxygen input (S.O.I.), metalloid content, etc.—and, therefore, shows a marked degree of scatter. From this it can be inferred that there are wide differences in the efficiency of oxygen utilization with respect to carbon removal. It is quite apparent that consideration of the S.O.C. alone in order to assess the efficiency of oxygen, as has been done in the past, is of little or no value, except to indicate some dependence of the S.O.C. on the initial carbon content.

The Effect of High Specific Oxygen Input Rates

Occasionally exceptional S.O.I. rates, some as high as 450 cu.ft./min./ton, were deliberately used in the resistor rod furnace. These high input rates caused great variation in the S.O.C. values. In the case of heats made in member foundries, the S.O.I. values were in the main less than 150 cu.ft./min./ton. Applying the following conditions: (a) the temperature prior to injection was not less than 2876 degrees F, and (b) the initial carbon was greater than 0.25 percent, and the final carbon greater than 0.10 percent, a relationship between S.O.I. and net S.O.C. was determined as indicated in Figure 2. From this it is clearly seen that at S.O.I. rates in excess of 150 cu.ft./min./ton, the variation in S.O.C. rates increases indicating inefficiency in carbon removal. This conclusion is not unexpected, and, in fact, the practice in member foundries is to inject at rates lower than 150 cu.ft./min./ton. The object in presenting this conclusion is to allow the omission of further consideration of heats blown at rates in excess of this amount. The likely cause of inefficiency at these excessive S.O.I. rates is that the input rate of oxygen is faster than the reaction rate, due to lack of sufficient time of contact between oxygen and the metal.

The Effect of Metalloids other than Carbon on the Efficiency of Carbon Removal

The efficient use of oxygen for carbon removal is dependent on the relative affinities for oxygen of the elements present. When an element having a greater affinity for oxygen than carbon is present, it will be oxidized preferentially and the carbon removal will not occur until, either by the influence of activity, mass or temperature, the balance is swung in favor of carbon removal. The time elapsed from the start of injection to the initiation of the carbon flame serves as a rough indication of the metalloid content. If this time is great, i.e., the metalloid content is high, then, all other factors being equal, the over-all time of injection will be prolonged and the efficiency of

TABLE I

EFFECT OF METALLOID CONTENT ON EFFICIENCY OF OXYGEN USAGE

		Heat Number		
		J56B	J75A	J56C
Carbon	Initial	0.51	0.54	0.49
	Final	0.50	0.47	0.33
Manganese	Initial	0.28	0.51	0.10
	Final	0.17	0.34	0.04
Silicon	Initial	0.07	0.03	0.03
	Final	0.03	0.02	0.02
Temperature, Initial °F		2732	2732	2750
Time of Injection, secs.		36	39	36
Time to Carbon Flame, secs.		no flame	28	5
Specific Oxygen Input		138	125	116
Specific Oxygen Consumption		87	11.5	4.4
Over-all Efficiency of Oxygen Utilization (Carbon and Metalloids)		27%	50%	

carbon removal will be decreased. This is indicated from the data concerning three heats similar in respects other than metalloid content shown in Table I.

The S.O.C. fell from 11.5 cu.ft./0.01 percent C/ton in the case of J75A to 4.4 cu.ft./0.01 percent C/ton in the case of J56C. The conclusion from this is that only the oxygen used after the initiation of the carbon flame is utilized efficiently. On this basis, the following experimental procedure was adopted.

In all heats the time that elapsed from the start of the oxygen injection to the initiation of the carbon flame was noted. From this time and knowing the over-all time of injection and the rate of injection, the volume of oxygen used during the period of the carbon flame was calculated. The volume was used to calculate the "net specific oxygen consumption". This assumes that no carbon is removed prior to the appearance of the carbon flame. This method of calculating the net S.O.C. was applied to all heats where the initial carbon content was in excess of 0.1 percent, i.e., heats in which the carbon flame was quite definite. In the case of initial carbon contents below 0.1 percent, it was assumed that carbon was removed throughout the period of injection, since (a) in plain carbon steel, when the initial carbon content is low, the concentration of other elements is also low, and (b) when the initial carbon content is low, the carbon content is the overriding factor and the interfering effect of other elements is comparatively small. For such heats the S.O.C. is the same as the net S.O.C.

The net S.O.C. values versus initial carbon content are plotted in the form of isotherms corresponding to 2732 degrees F and 2912 degrees F in Figure 3. This graph relates to all the heats made in the resistor rod furnace, heats from B.S.C.R.A. member foundries where the relevant data are known, and data from other workers[2].

The Effect of the Metal Temperature Prior to Injection

As shown in Figure 3, the effect of temperature appears to be small at low carbon contents, and it is only with initial carbon contents greater than 0.08 percent that the isotherms of 2732 degrees F and 2912 degrees F are separate. Although the difference between these isotherms does not appear to be unduly marked, it must be remembered that at the higher temperature, the total metalloid content of the bath is less, due to oxidation, and, therefore, the efficiency of oxygen utilization for carbon removal is greater at the higher temperature. These isotherms were used to construct control charts and in these the differences assume appreciable proportions.

Derivation of Control Charts for Carbon Removal

Knaggs[1] formulated a control chart based on total S.O.C. values. Using the same method, but applying the net S.O.C. values, control charts have been constructed for 2732 degrees F (Figure 4) and for 2912 degrees F (Figure 5). The volume of oxygen referred to in these charts is that required *after* the initiation of the carbon flame. By this means the necessity of having any prior knowledge of the metalloid content of the bath is eliminated. These charts may, therefore, be used in foundries to secure the most economical use of oxygen to remove a predetermined amount of carbon from the bath, and their general applicability is at present the subject of investigation in collaboration with several members of the B.S.C.R.A.'s Steelmaking Advisory Committee.

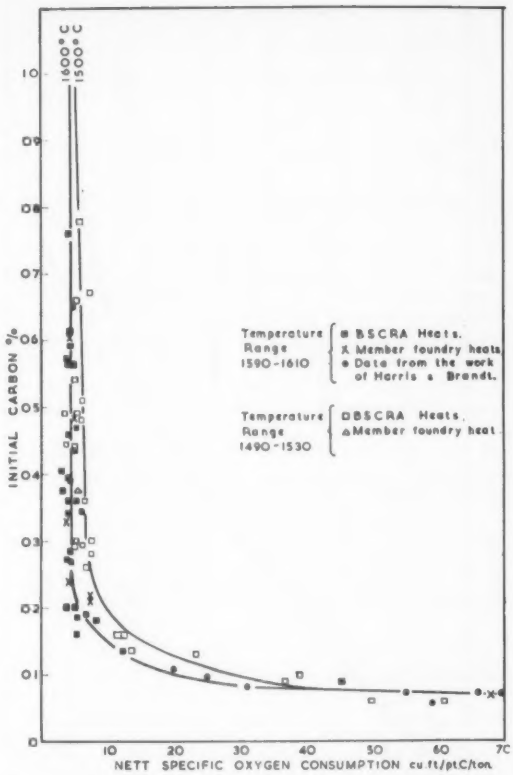

Figure 3—Isotherms relating initial carbon content and net specific oxygen consumption at 2732 degrees F and 2912 degrees F.

Conclusions

The factors affecting the efficiency of carbon removal by oxygen injection have been considered and accounted for in qualitative fashion. From this a quantitative measure of the efficiency of oxygen utilization for carbon removal has been established by measurement of the oxygen used after the initiation of the carbon flame. Control charts for operation at 2732 degrees F and 2912 degrees F have been constructed, based on the data obtained which show the volume of oxygen required to remove a desired quantity of carbon from any particular initial carbon level. These charts are applicable when the following

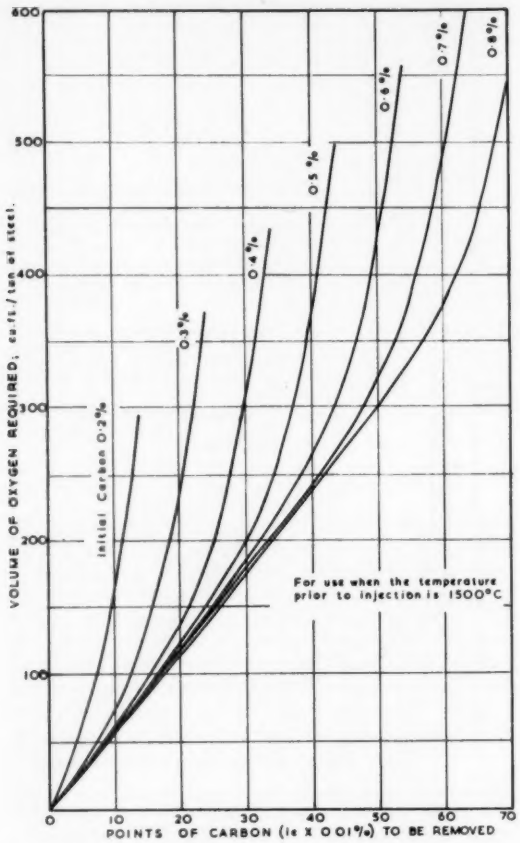

Figure 4—Control chart for oxygen usage for injection temperature of 2732 degrees F.

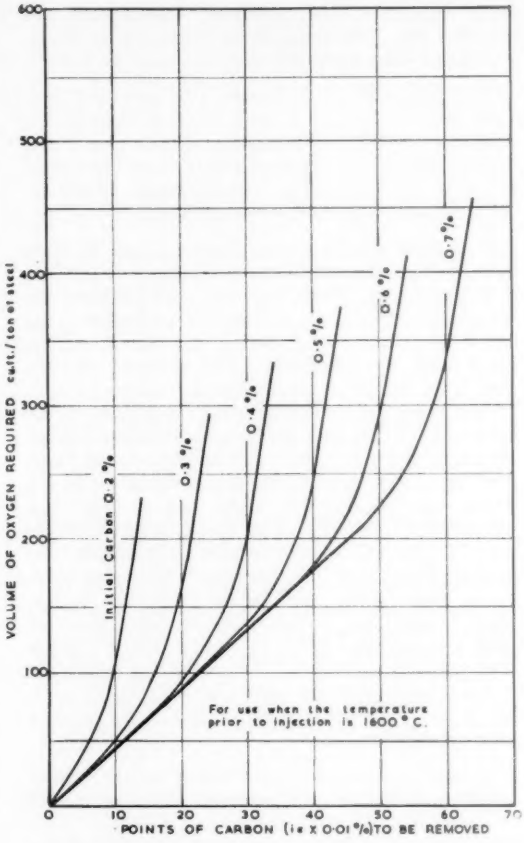

Figure 5—Control chart for oxygen usage for injection temperature of 2912 degrees F.

conditions are fulfilled: (a) the metal temperature is as stated on the chart; (b) the specific oxygen input rate is less than 150 cu.ft./min./ton (this condition already obtains in B.S.C.R.A. member foundries); (c) the calculated volume of oxygen required is measured after the initiation of the carbon flame.

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1. Knaggs, K., "Oxygen Injection in Foundry Steelmaking Practice", *Journal of Steel Castings Research,* No. 12, September 1958.
2. Harris, T. H., and Bandt, D. J. O., *J. Iron & Steel Inst.,* 1950, 165 (2), 399-410.

NEW POLICY FOR THE JOURNAL OF STEEL CASTINGS RESEARCH

The January 1960 issue of this Journal will inaugurate a new policy of publication which has been decided upon by the Society's Board of Directors. The Journal will be published 4 times a year on a quarterly basis instead of 3 times a year which has been the practice in the past. Also, the Journal is to be made available to professors of engineering at various universities, at their request. The professors at the universities which are active with the Foundry Educational Foundation will automatically receive copies of the Journal.

The Journal will contain information on steel casting research carried on throughout the world as it does at present, and it will also contain information and reports on SFSA research studies. Also, an effort will be made to secure and publish condensations of these on steel casting technology prepared by students, and research reports prepared by professors and their students.

Abstracts of technical publications covering research studies published in transactions of engineering societies and technical journals also will be published in the Journal in the future.

A STUDY ON BLOWHOLES IN IRON AND STEEL*

by

Takehiko Fujii**

Composition of Gases in Blowholes

In any study of blowhole elimination, it is first necessary to identify the gases present. For this purpose, a vacuum-cutting apparatus was designed. This apparatus consisted of a lathe working in high vacuum. During cutting with this apparatus, two kinds of gases were extracted, one from the blowholes or pinholes and the other from the chips. The apparatus was designed to prevent these gases from mixing.

Blowhole samples were cast from molten steel containing absorbed oxygen or hydrogen. The gases discharged from blowholes during the vacuum-cutting operation were collected by a mercury-diffusion pump and a jet mercury pump, then analyzed with an Orsat micro-analysis apparatus. Chemical compositions of gases in blowholes were as follows:

1. Gases were for the most part hydrogen and nitrogen, while CO, CO_2 and CH_3 were present in very small quantities.
2. Free oxygen was present in small amounts.
3. Gases present in non-deoxidized steel were for the most part nitrogen, with hydrogen present in small amounts. Gases present in deoxidized steel were for the most part hydrogen with nitrogen present in small amounts.

From this composition, it was presumed that CO gas originally was present in the blowholes. This gas decomposed during cooling, and the pressure in the blowholes was reduced. Hydrogen and nitrogen were then able to diffuse into the blowholes from the surrounding steel.

Formation of Blowholes by CO Gas and Deoxidation

Blowholes caused by CO gas are found in rimmed steel, but, due to deoxidation, are not present in killed steel. The limiting amounts of deoxidizers required to eliminate blowholes have been calculated from the equilibrium constant, but heretofore have not been determined experimentally. The results of experiments using the vacuum-cutting apparatus will be shown here.

Blowhole samples were melted in a 220-pound basic, high-frequency induction furnace. The deoxidizer (either Si, Mn, or Al) was added in various quantities when the temperature of the molten steel reached 2910 degrees F. Oxygen gas was lanced into the molten steel for 30 seconds after deoxidation, and by the reaction of carbon and oxygen, CO gas evolved violently. Fifty-five pounds of molten steel were immediately tapped into a ladle and then poured into a 35-pound ingot mold. In succession, oxygen gas was lanced again to the rest of the molten steel in the furnace for 30 seconds, and 55 pounds of steel were again tapped and poured into ingot molds. Accordingly, from each melt of 220 pounds, four ingots were obtained, each containing different amounts of silicon, manganese, or aluminum and oxygen. These ingots were cut lengthwise and the blowholes investigated. The results obtained from these experiments were as follows:

1. Blowholes by CO gas were the same as in rimmed steel, even if carbon content was higher than that of usual rimmed steel; both primary and secondary blowholes were present.
2. When deoxidized by silicon, the maximum amount necessary for complete elimination of blowholes was 0.10 percent for steel containing 0.33 to 0.40 percent carbon, and 0.20 percent for steel containing 0.40 to 0.80 percent carbon. This limit was raised by carbon content and corresponded to a curve which was calculated from equilibrium considerations.
3. The maximum amount required for complete elimination of blowholes when deoxidized by aluminum was 0.10 percent.
4. When deoxidized by manganese, blowhole formation was not eliminated due to its weak deoxidation power.

The Formation of Blowholes by Hydrogen and Nitrogen in Killed Steel

In semi-killed or killed steel, hydrogen or nitrogen becomes a factor of blowhole formation because the pressure of CO gas in molten killed steel is very low, and the solubility difference of hydrogen or nitrogen in molten and solid steels is large.

Blowholes caused by CO gas have already been discussed. Now blowhole formation by hydrogen and nitrogen will be explained. The procedure was similar to that used in the CO gas study. Blowhole samples were melted in a 220-pound basic, high-frequency induction furnace. The deoxidizer (silicon or aluminum) was added to the melt at 2910 degrees F. Hydrogen or nitrogen gas was lanced into the melt after deoxidation. Fifty-five pounds of molten steel were immediately tapped into a ladle and poured into a 35-pound ingot. Four ingots in succession from each heat were cast in this manner.

The results obtained were as follows:

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*From a summary of a series of articles appearing in Tetsu-to-Hagane Abstracts, Vol. 42, 1956.

**Sumitomo Met. Ind. Ltd.

1. Blowholes caused by hydrogen:
   a. Silicon deoxidation: as the hydrogen content increased, the amount of silicon needed to limit blowhole formation increased from 0.10 percent to 0.20 percent. Hydrogen gas content was not found to be less than 8 p.p.m., even when silicon content was greater than 0.20 percent.
   b. Aluminum deoxidation: the hydrogen content was found to be reduced to a minimum of 0.8 p.p.m. at an aluminum content of 0.01 percent or greater. This indicates that hydrogen is not the main cause of blowhole formation if the molten steel is fully deoxidized.
2. Blowholes caused by nitrogen:
   a. Silicon deoxidation: as the nitrogen content increased, the amount of silicon needed to limit blowhole formation increased from 0.10 percent to 0.20 percent. Higher silicon contents were found to reduce nitrogen gas content to a minimum of 100 p.p.m.
   b. Aluminum deoxidation: as nitrogen content increased, the amount of aluminum needed to limit blowhole formation increased to 0.08 percent. This illustrates that in the case of aluminum deoxidation, where hydrogen content is less than 0.8 p.p.m., nitrogen gas is probably the main cause of blowhole formation.

Some Examples of Blowholes Caused by Hydrogen

In spite of the above observations, blowholes are often found in steel castings or large killed ingots even if hydrogen gas content is as low as 3 to 5 p.p.m. Accordingly, to clarify the cause of blowhole formation in steel castings or large killed ingots, additional experiments were carried out.

The same molten steel was cast in steel molds and sand molds, all of the same size and shape. Sand molds were heated at 210 degrees F for 2 hours, 570 degrees F for 2 hours, and 1260 degrees for 2 hours before casting. These cast samples were cut and analyzed with the vacuum-cutting apparatus, and the following results were obtained:

1. It was clear that moisture of sand molds decomposed and became a cause of blowhole formation. A heating temperature of 210 degrees F for 2 hours was found to be insufficient for elimination of blowholes. The moisture absorbed from the atmosphere was a cause of blowhole formation when the sand molds were left sitting for long periods.
2. Small specimens were taken from the center of a 12-ton killed ingot and analyzed with the vacuum-cutting device. The discharged gas was found to be primarily hydrogen. This hydrogen was present in the steel in quantities of 12 to 15 p.p.m. Also, the hydrogen gas pressure in δ iron was greater than 1 atmosphere and was hence a potential cause of blowhole formation.

GREEN TENSILE STRENGTH OF CLAY-BONDED MOLDING SANDS AND THE INFLUENCE OF ACTIVATION ON THE GREEN TENSILE STRENGTH

by

W. Patterson and D. Boenisch*

Characterization of the Green Tensile Strength of Molding Sands

The values obtained by present day sand testing procedures do not allow any conclusions to be drawn as to the sand properties during pouring, because the tests are carried out at room temperature and with a homogeneous distribution of temperature and material in the molding mixture.

It is well known that temperature disturbs the equal distribution of moisture in green sand mixtures. Heating the surface of molds causes a temperature gradient in the sand, and it causes moisture, in the form of steam, to be lost from the heated layers of the mold. The greater part of the water vapor formed will permeate through the porous molding material and will condense in the colder regions of the sand mold, thus causing a supersaturated zone to be set up inside the mold. This zone will lie parallel to the surface of the mold and, as the heating time increases,

* A translation from the German article in Giesserei, 1958, 45 (19), 11 Sept., 565-567.

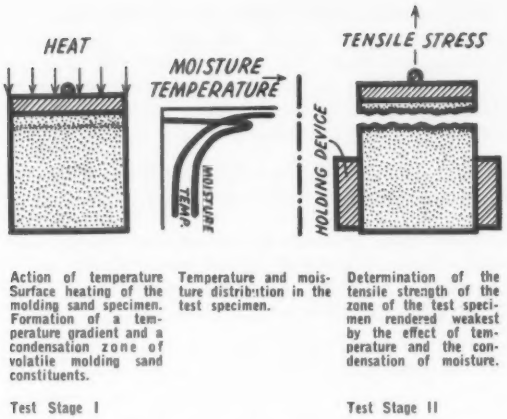

HEAT
MOISTURE
TEMPERATURE
TENSILE STRESS
HOLDING DEVICE
TEMP.
MOISTURE
Action of temperature Surface heating of the molding sand specimen. Formation of a temperature gradient and a condensation zone of volatile molding sand constituents.
Temperature and moisture distribution in the test specimen.
Determination of the tensile strength of the zone of the test specimen rendered weakest by the effect of temperature and the condensation of moisture.
Test Stage I
Test Stage II

Figure 1—Diagrammatic representation of the wet tensile strength tests.

the zone will be displaced towards the interior of the mold. This process occurs mainly in green sand molds, that is, molds which are poured without drying after molding. It can also occur in air dried or artificially dried molds if they have reabsorbed moisture from the atmosphere after drying or if the bonding clay gives off water of crystallization during pouring.

The high moisture content and temperature (about 110-175 degrees F) in the condensation layer greatly reduce the strength of the molding sand.

The tensile strength of this sand layer, which amounts to only a fraction of the normal green compression strength, is called the green tensile strength, N. Green tensile strength is a measuring unit which offers better possibilities in evaluating than the old classical method of sand testing.

Green Tensile Strength Testing

Figure 1 is a diagrammatic representation of a new test procedure for determining green tensile strength. A temperature gradient is established by heating the face of a standard test specimen. This causes a supersaturated sand layer of reduced strength to be set up several millimeters from the face of the test specimen. The specimen is ruptured by applying a tensile stress. The quotient of the rupture stress and the cross sectional area of the specimen (19.6 sq. cm.) is the green tensile strength.

Significance of the Green Tensile Strength

The green tensile strength gives a quantitative evaluation of the adhesion strength of the molding sand surface which was dried by the heat of the liquid metal. The green tensile strength also gives a measure of the degree of activation, the thermal stability, and the effective surface of the bonding clay.

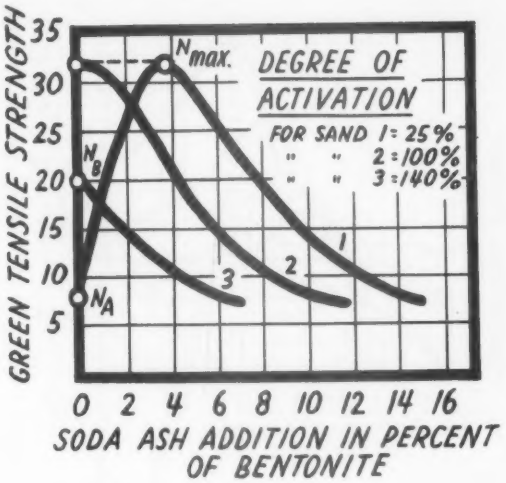


Figure 2—Activation curve of a synthetic molding sand suitable for molding containing 6 per cent of bentonite from Mainburg; the initial degree of activation of the bentonite varies.

All increases in the green tensile strength, due to additions of activating salts, are regarded as activation. The best known activating agent is soda ash.

Activation Curves†

An example of an activation curve of a synthetic molding sand is given in Figure 1 and it shows the changes in the green tensile strength with increasing additions of soda ash. Curve 1 is valid for a non-activated calcium bentonite as a sand bonding agent. The initial value of the green tensile strength, before the first addition of the activating agent, is designated N_A. The green tensile strength increases as increasing amounts of soda are added and a maximum value, N_{max} is obtained when a given quantity of soda is added. This maximum value represents the optimum of activation ($\eta = 100$ percent activation). Further additions of soda ash cause a decrease of the green tensile strength; under these conditions, the sand is over-activated. The best workable condition and utilization of the binding clay are, therefore, obtained by the addition of the optimum quantity of a particular activating agent.

The initial value of the green tensile strength, N_A, may vary if the sand has already been partially activated with soda ash during mulling, or if the bonding clay has already been treated by the manufacturers. N_A may then be found to be close to N_{max} or may even correspond to N_{max} (Figure 2, curve 2).

† Activation refers to the benefaction of a clay or molding sand through the addition of soda ash and the resultant change in pH.

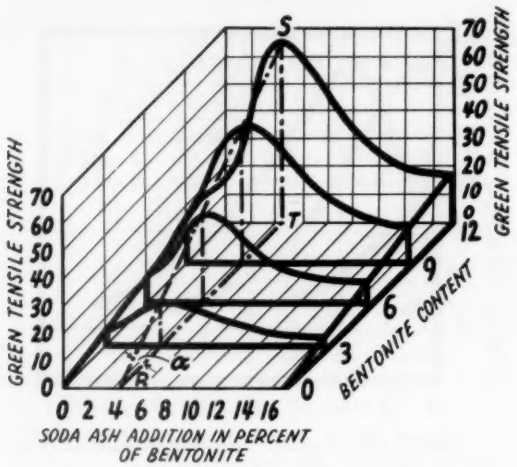


Figure 3—Wet tensile strength peaks of a synthetic molding sand. Bonding clay: calcium bentonite from Mainburg; molding sand moisture content at all times suitable for molding; basic sand: Nivelstein; average grain size = 0.23 mm, degree of uniformity = 75 per cent.

If the sand has been treated with too much soda ash (over-activated), then the N_{max} value does not occur in the activation curve (Figure 2, curve 3). The initial value of over-activated sands is designated as N_B. Over-activated sands can be reclaimed by additions of nonactivated clays. A new activation curve will then show if the sand has become under-activated. Only then can an exact N_{max} value be established.

Degree of Activation

The degree of activation η for a fixed activating agent (x) for under-activated sands can be calculated according to:

$$\eta_x = \frac{N_A}{N_{max}} \times 100 \text{ (percent)} \quad (1)$$

and for over-activated sands:

$$\eta_x = \frac{N_{max} + (N_{max} - N_B)}{N_{max}} \times 100 \text{ (percent)} \quad (2)$$

This shows whether a sand can still be activated or whether it is over-activated.

Index of Quality of Bonding Clays

Figure 3 is a spatial representation of the relationship between the green tensile strength of the molding sand, the bonding clay content, and the quantity of activating agent added. The rise Tan α along the dotted line (RS, Figure 3) in green tensile strength peaks is a measure of the quality of the bonding clay:

$$\text{Tan } \alpha = \frac{TS}{TR} = \frac{N_{max}}{\text{percent bonding clay}}$$

= specific maximum green tensile strength (3)

The minimum green tensile strength that will yield quality castings can vary, and must be determined empirically. From the three-dimensional diagram for the mold sand in question, the quantities of bonding clay and activating agent (soda ash) necessary for attaining this minimum value can be read off.

The use of the green tensile strength test yields the following technical and economical advantages:

1. In place of activated bentonites, cheaper, nattural calcium bentonites can be used, which can be treated with soda ash during sand preparation. This, in turn, gives the following advantages:

   a. It has been shown quantitatively that the susceptibility of sand to expansion defects, such as veins, rat tails, and scabs is closely related to the green tensile strength. These defects are reduced with an increasing degree of activation. They reach a minimum for an activation $\eta_x = 100$ percent.

   b. The thermal stability of the binder reaches its maximum at an activation of 100 percent. Optimum activated sands, therefore, possess a maximum thermal resistance and minimum abrasion susceptibility.

   c. An increase in green tensile strength resulting from soda ash additions enables savings to be made in molding material additives used to reduce or eliminate expansion scabs. Thus the undesirable effects of large quantities of such additives as woodflour, pitch, coaldust, dextrine, etc., are also reduced.

2. Tests have shown that many naturally bonded molding sands can be activated, and it is not necessary that these bonding clays should be capable of swelling. Thus it is possible to employ natural clays which are not bentonites for making semi or completely synthetic molding sands. So treated sands are, therefore, less susceptible to scabs and other sand expansion defects.

3. Uniform molding sand properties can be maintained through periodic checks of the green tensile strength of the sand and, when necessary, soda ash additions can be made.

4. The common practice of improving natural sands by additions of bentonite can be eliminated or the amount of bentonite reduced through the activation of these natural sands (treated with soda ash).

5. The quality and uniformity of the delivered bentonites and clays can be quantitatively determined by means of the wet tensile test. The degree of activation of synthetic sodium bentonites can also be determined and the optimum activation can be obtained by adding activating agents or nonactivated clays, even if the delivered bentonites were incorrectly activated.

QUICK-DRYING CORES AND MOLDS

by

A. M. Ljass and I. B. Kumanin

This is a development of investigation carried out by Zniitmasch (Russian Foundry Research Laboratory), which permits the classification of binders for molds and cores as well as of their technological properties, corresponding to the requirements for sand mixtures.

This classification determined the development of mixtures with new technological properties; organic and inorganic irreversibly solidifying binders of the first group (that is, materials having the maximum effectiveness). Members of the first group that are insoluble in water (Class A) were not used because the processes occurring during drying, oxidation, polymerization and the colloidal changes which follow it are slow. The work carried out by the authors in 1949, showed that a series of organic and inorganic binders of other classes can, in catalytically hastened solidification (so-called quick-drying mixtures), considerably shorten the drying time of cores and molds.

During the years 1949 - 51, a considerable number of quick-drying mixtures of different composition were examined in Zniitmasch. This paper gives a short description of only two groups of these—those most commonly used: (a) with synthetic resins (organic binder), and (b) with water-glass and caustic soda (inorganic binders).

Quick-Drying Mixtures Using the Binder MΦ 17

It was previously found by the authors that those binders which are distinguished by an irreversible solidification display the greatest specific strength. This investigation was, therefore, limited to thermosetting resins, urea-formaldehyde resins being chosen out of this group. The investigations showed that phenol-formaldehyde resins are also suitable for the production of quick-drying mixtures. This is not further discussed here, as the basic research was carried out with urea-formaldehyde resins.

The use of these resins for cores is based on their condensation and setting properties. The relatively low mechanical strength of the solidified urea-formaldehyde resins is a result of their uneven physical-mechanical structure and the presence of a large number of low molecular compounds and of porous patches. The resins must contain higher molecular and chemically identical complexes in order to increase their mechanical strength. This can be achieved by modification with alcohol.

The Russians have worked out the production of this new material by condensing the urea with formaldehyde followed by the modification of the condensation product with higher alcohols (butyl alcohol) or alkali resins containing functional hydroxyl groups. The experiments carried out in Russia led to the development of a special urea-formaldehyde resin called MΦ 17, that is at present manufactured by the factories of the Ministry of Chemical Industry. The main problem was speeding up the setting of resin. This can be achieved by the addition of catalysts. It is also known that the heating of a reactive resin speeds its conversion to a non-melting insoluble state.

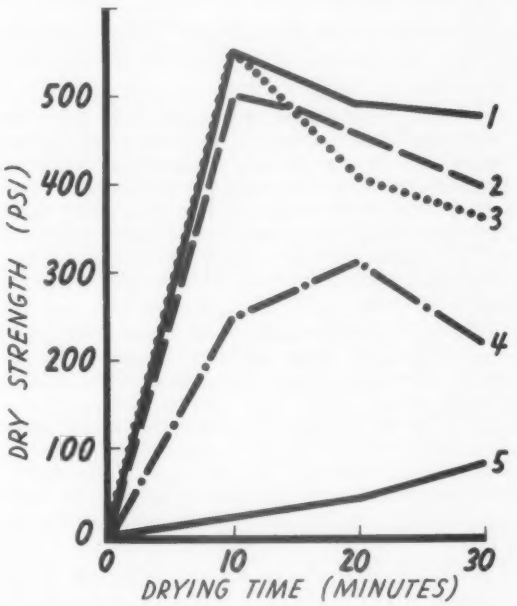


Figure 1—The influence of the catalysts on the properties of sand mixtures containing the binder MΦ 17.

1) nitric acid; 2) hydrochloric acid; 3) oxalic acid; 4) without catalysts; 5) with the binder ГУ4.

The experiments carried out in Zniitmasch with neutral, acid and alkali solutions of MΦ 17 have shown the great influence of the catalyst on shortening the drying of cores and on their strength. These experiments have shown that the use of acid catalysts markedly shortens the drying time for cores and nearly doubles the strength of dry cores. The changes in the strength and drying times of core mixtures containing MΦ 17 with the addition of various acids are shown by Figure 1. For comparison, the curves showing the changes in strength with various drying times of mixtures containing MΦ 17 without acid and for the binder ГУ4, which is well known in foundries, are included.

The pH value of the solution has a decisive influence on speeding the drying time and on the strength of the dried core. The best results are obtained when the pH of the catalyzing solution is 0.75. The kind of acid used to bring about the change of the pH value does not matter very much. Industrial nitric acid is the cheapest catalyst.

The experiments showed that alkali solutions slightly shortened the drying time but did not alter the strength of the dried cores.

The fact that catalysts (acids) not only speed the hardening but also influence the mechanical properties of the cores has led to the important conclusion that they cause the formation of complex resin compounds with longer chains and of more uniform composition. This led to further investigations by the authors of the combined application of MΦ 17 and other acid binders, including alcoholic alkali sulphites in core mixtures.

The quickened hardening of the resins in the presence of a catalyst is best shown on heating. The investigations showed that the addition of a certain quantity of acid (pH value) and the heating of the core to 392 - 428 degrees F shortened the setting time of the cores (i.e., drying out) considerably, compared with existing methods. On the basis of the laboratory experiments and their testing in practice, new quick-drying mixtures were developed as shown in Table I.

Below are given the particulars of the new technological process using quick-drying mixtures which considerably influence the quality and production of castings and lead to a reduction of the production area.

1. The cores are made of mixtures that ensure a strength of the dried cores up to 569 psi, whereas the usual mixtures give a strength of only 142 - 170 psi.
2. The strength of the new mixtures cannot be attained by the binders previously used in foundries, because of their low strength and because their amount must be kept low to avoid excessive gas formation.

   A comparison of the specific strengths of various binders gives the following results:

   1. MΦ 17 with a catalyst 284 psi
   2. Linseed oil 88.5 psi
   3. Petrow's oxidized catalyst (Harter 11) 88.5 psi
   4. Oil varnish Oksol 72.6 psi
   5. Peat varnish 14.2 psi
   6. Alcoholic alkali sulphite 11.4 psi

3. Mixtures with MΦ 17, containing catalysts, set remarkably quickly (Table II) and at the same time have great strength.
4. In the application of quick-drying core mixtures, the cores can dry during transport from the manufacturing place to the mold. This working method can be used in series production. Drying chambers are no longer necessary. If, on introduction of the new method, one fully utilizes the existing foundry equipment, then, by the reduction of the drying time, part of the drying chamber becomes vacant. This frees working space, and the total production of the foundry will increase.
5. The investigations showed that the use of cores with greater strength improves working conditions and considerably decreases defective castings due to sand inclusions and other faults. The work of cleaning of the castings is correspondingly reduced.

TABLE I

COMPOSITION AND PROPERTIES OF QUICK-DRYING MIXTURES

Sand Mixtures for:	Composition of the Sand Mixture						Properties			
	Sand-Clay Portion (Weight Percent)			Amount of Binder (Weight Percent of Sand-Clay Portion)			Strength			
	New Sand	Old Sand	Clay	Binder MΦ 17*	Alkali Sulphite	Total Clay Content (Percent)	Green Compression Strength (psi)	Dry Tensile Strength (psi)	Gas Permeability	Moisture (Percent)
Cores 1st class	100	–	–	1.5-2.5	-	up to 2.0	0.43-1.00	356-498	180	2.0-3.0
Cores 2nd class	97	–	3	2.0-2.5	2.0-2.5	3.0-5.0	2.13-2.56	284-427	150	2.5-3.5
Cores 3rd class	95**	–	5	2.0-2.5	2.5-3.0	5.0-7.0	2.42-3.13	256-356	130	2.5-3.5
Cores 4th class Cores 5th class	Sands mixed with water-glass are recommended.									

* To the sands which contain no sulphite, there is added a quantity of 10 percent oxalic acid solution equal to 25 percent of the weight of the binder MΦ 17. The acid is added to the binder immediately before use.

** The addition of 40 percent of old sand is permissable.

TABLE II

COMPARISON OF DRYING TIMES

Core Size	Drying Time (Minutes)	
	Old Method	New Method
Small	90-180	5-30
Medium	360-480	30-60
Large	480-720	60-120
Medium with Template Molding	600-840	60-120
Large with Template Molding	1080-1680	90-150

6. The use of especially firm mixtures makes the venting of large cores unnecessary, which increases the productivity of coremakers, especially in foundries employed in heavy machine and tool making. For the same reasons core bars become lighter and in many cases superfluous.

7. If high quality mixtures are used, solid cores are often no longer necessary. Hollow cores with wall thicknesses of 1.2 to 1.6 inches can be produced. Due to the great strength of the outer layer, the interior can be made of used sand or even filled with dry sand. By this means the use of basic and auxiliary material can be reduced and the drying time is still further reduced.

8. In mass production foundries, where cores are blown, hot air can be used for blowing, the drying time being reduced at the same time. Core blowing plants with large sand containers can carry the following processes in succession: a) blowing of cores by the usual method, and b) blowing hot air through the cores in the same core box without removal. This process completely dispenses with drying ovens (also with straight flow furnaces), special core drying plants and, therefore, considerably speeds up the entire production of cores.

9. When the castings have cooled, the cores collapse and need only be shaken out.

Quick-Drying Mixtures Using Water-glass and Sodium Hydroxide

A quick drying of cores and molds containing water-glass is achieved by:

1. Cold carbonic acid
2. Warm carbonic acid
3. Hot waste furnace gases containing CO_2
4. Gas or natural oil burners

During these processes, the mold is not dried by complete vaporization of the moisture, but by combining vaporization with the chemical binding of the water to the hydrogel of the silicic acid and to soda. By this means drying can be limited to the surface layer of the mold. In "chemical drying", there is poor diffusion of the water in the mold and any moisture which penetrates to the surface is absorbed by unsaturated compounds.

Zniitmasch recommends the drying of molds by hot gases from transportable driers which contain approximately 10 to 11 percent CO_2. Hot waste furnace gases can also be used. This by no means exhausts all the possibilities of drying cores and molds. One must above all consider the possibility of adding salts to the water-glass, such as NaCl, $CaCl_2$, $MgCl_2$, NH_4Cl, etc. The addition of salts speeds the coagulation of the silica and the formation of a thin skin of silicic acid. The same results can be achieved by the addition of gypsum or sodium silicon fluoride. An examination of the practical application of these catalysts has still to be made.

As in all lyophillic colloidal systems, the formation of the silica gel is shown by the coagulation of the colloidal particles. The developing mass gradually attains an increasing strength. The quantity of water contained in the silica gel determines its quality. The coagulation of the colloid may proceed only very slowly. The duration of this process determines the end of the solidification of the water-glass. If the increasing strength of the mold is taken as a criterion, one cannot regard coagulation as completed even after the standing of the mold in air for 20 hours. A considerable speeding up of the gel formation can be produced by a change of temperature and of pH value, as well as by the use of catalysts.

The above observations led to very important conclusions about the practical application of sands containing water-glass. Investigations showed that the addition of alkalis to the mixtures slowed down the hardening in air but did not affect their hardening when heated. To ensure that these water-glass containing molding sands have the desired technological properties in a green state, especially great strength, one must add clay which, however, considerably decreases the strength of the dry mold. Due to this, mixtures of quartz sand, water-glass and clay do not attain the technological properties necessary for molding sand and for finished molds and cores, which can be achieved by the new methods.

Investigations carried out by the authors show that the addition of sodium hydroxide fundamentally alters the properties of the molding sand mixtures and correspondingly affects the molds and cores. The addition of a 10 to 20 percent solution of sodium hydroxide increases the strength of the dry molds 6 to 8 times, and the strength of green molds 1.5 to 2 times. It considerably improves their plastic properties and increases the "life span" of the mixtures.

TABLE III

COMPOSITION AND PROPERTIES OF MIXTURES CONTAINING WATER-GLASS

Composition of the Sand-Clay Parts (Weight Percent)			Water-Glass in Weight Percent of the Sand-Clay Portion	"Masut"* in Weight Percent of the Sand-Clay Portion	Caustic Soda (10% Solution) in Weight Percent of the Sand-Clay Portion	Total Clay Content (Percent)	Green Compression Strength (psi)	Dry Tensile Strength (psi)	Permeability	Moisture (Percent)
New Sand	Old Sand	Clay								
97-95	-	3-5	5-7	0.5	1	3-7	2.84-4.98	213-284	100	3.5-4.5
70	30	0-2	5-7	0.5	1	3-7	3.56-5.69	213-284	100	3.5-4.5

* Presumably an organic additive

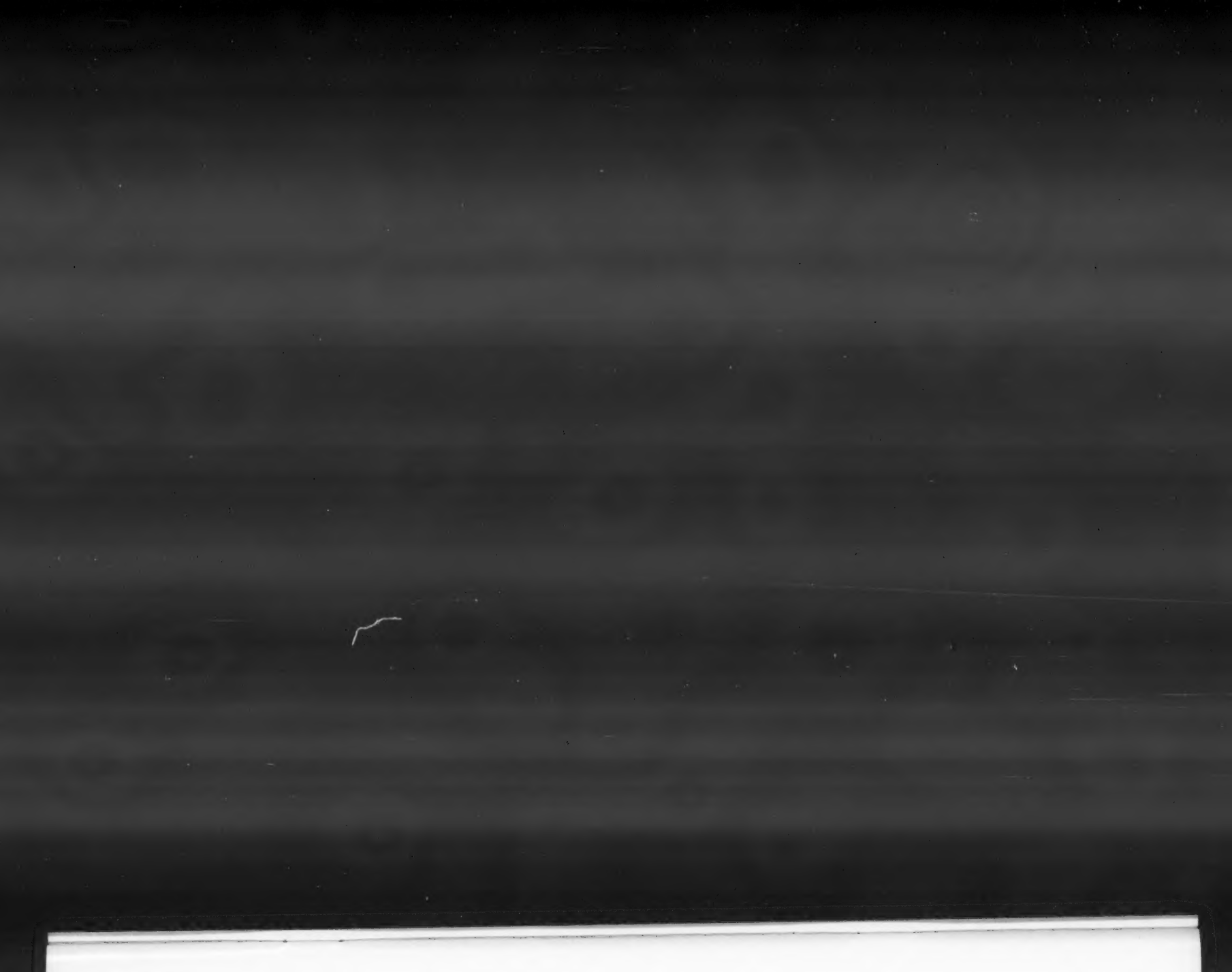
TABLE IV—COMPARISON OF MOLD DRYING TIMES

Mold Dimensions - Combined Cope and Drag (Inches)	Drying Time (Minutes) Old Method	New Methods
23.6 x 19.7 x 23.6 to 47.2 x 31.5 x 31.5	360 - 480	10 - 15
39.4 x 31.5 x 31.5 to 118 x 78.7 x 39.4	480 - 720	20 - 30
118 x 78.7 x 39.4 to 196 x 118 x 55.1	960 - 1440	30 - 50

By means of laboratory and works experiments, new mixtures of quartz sand, clay, water-glass and sodium hydroxide were developed (Table III), and were found to have a great practical application. New compositions of mixtures and new drying methods produced working methods for quick drying molds and cores which can be applied to medium and large steel castings.

The advantages of molds made with the quick-drying sodium silicate-sodium hydroxide molding mixes are as follows:

1. The molds are made of facing sand and backing sand; water-glass and sodium hydroxide are only added to the facing sand.
2. The molds are dried by the chemical bonding of the water. This "chemical drying" of the molds takes place at the place of working, by means of easily movable furnaces, which makes drying chambers superfluous.
3. The facing sand is produced from mixtures that have a dry tensile strength of 284 - 356 psi. This strength is about 10 times that of the norm of present working methods.
4. Due to their great strength, molds for large castings can be produced without core bars.
5. The great strength of these sand mixtures enables the filling, after ramming, of the remaining part of the mold with any dry sand. This dispenses with hard ramming of the molding sand, which at present consumes most of the production time of large molds. The consumption of molding sand and the time taken in the preparation of the sand are also considerably reduced.
6. The chemical drying of the molds is carried out according to the data given in Table IV. Through the reduction of the mold drying time, serial production can also be used for large single pieces.
7. These very strong sand mixtures decrease (to the point of disappearance) the wastage through sand inclusions, scabs and other defects which are caused by the mold. Due to this, the work of repairing castings is also considerably lessened.
8. In many cases when using quick-drying mixtures, the molds do not have to be washed, as water-glass helps to avoid penetration.
9. The production of cores of the 5th, 4th and partly of the 3rd class, of core sand containing water-glass and sodium hydroxide is recommended. For the other classes, quick-drying mixtures with the binder MΦ 17 should be used.

The above methods were employed successfully in the Wenjukow armature works, the Ural Machine Works, the Stalin Works, in Nowo-Kramatorsk, the Lenin-Newski Works, the Busuluk Works, the Lenin Works at Charkow and others. Castings of varying weights and shapes were produced, from a few pounds in weight up to 11.5 tons.

Through the use of new methods, the working time was shortened and the productivity of the molders, coremakers and cleaning room personnel increased, and a considerable decrease of faulty castings was achieved. Calculations showed that the application of the new methods reduced the cost of production for steel castings by 7 to 11 percent.